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## SEMINAR ON COMPUTER APPLICATIONS FOR THE CARDIOLOGIST—III*

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# Computer Technology: State of the Art and Future Trends

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**Computer technology and, more broadly, information technology, are bringing about a fundamental transformation in our society from an industrial economy to an information economy. A review of the short history and present state of information technology identifies two major undercurrents: 1) the miniaturization of computer components, which has produced a millionfold increase in the complexity possible in a single chip of silicon, and 2) the integration of four previously separate areas of information technology: computation, communication, databases and the user interface. Microelectronics, computer networks, data storage and user amenities are the basic technologies that support these four areas and stimulate their progress. Future trends in speech recognition, voice synthesis, artificial intelligence, expert systems, computational imaging and scientific workstations are also examined.**

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Computer technology is invigorating a fundamental transformation in our society from an industrial economy to an information economy. John Naisbitt, author of the best-selling book *Megatrends*, predicts that the resulting information society will not displace the previous industrial and agricultural societies, but will, through automation, shift the balance to information-intensive activities. Cardiology has been an information-intensive activity and so it is not surprising that it was one of the earliest of the medical specialties to utilize computers in an essential way.

Other articles in this series will discuss computer applications to cardiology. Here we concentrate on the technology itself and emphasize its relation to the information society and the breadth of the computer technology under discussion by substituting the phrase *information technology* or, as some now call it, *informatics*. This single word description of the field was originally popularized in Europe and is now gaining acceptance in the United States.

In order to project important trends for this technology in cardiology it is desirable to review its short history and present state. Table 1 shows one summary of the five generations of information technology covering the period from the construction of the first electronic computer, ENIAC,* to 1990. Two major undercurrents are responsible for the changes evident in this table. The first undercurrent is the steady miniaturization of computer components over the last 25 years that has produced a startling millionfold increase in the number of transistors that can be placed on a single chip of silicon at no increase in price. Moreover, increases in speed have accompanied this miniaturization so that today the amount of computation that can be carried out by that single chip has grown more than 10 millionfold. The second undercurrent is the integration of the four basic areas that make up information technology: computation, communication, data bases and the user interface. In the past these areas have been rudimentary or disjoint. Today we are beginning to see a few examples of the integration of all four areas within a single system. By the next decade this integrated approach will be the rule.

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*See the glossary at the end of this article for the full names of the acronyms and abbreviations used herein.



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**Table 1.** Five Generations of Information Technology*

| | Generation | | | | |
|---|---|---|---|---|---|
| | First<br>1946 to 1956 | Second<br>1957 to 1963 | Third<br>1964 to 1981 | Fourth<br>1982 to 1989 | Fifth<br>1990 and Beyond |
| Example computers | Eniac<br>Edvac<br>Univac<br>IBM 650 | NCR 501<br>IBM 7094<br>CDC-6600 | IBM 360, 370<br>PDP-11<br>Spectra-70<br>Honeywell 200<br>Cray 1<br>Illiac-IV<br>Cyber-205 | Cray XMP<br>IBM 308<br>Amdahl 580 | Extensive development of distributed computing<br>Merging of telecommunications and computer technologies<br>Extensive modularity |
| Telecommunications technology | Telephone<br>Teletype | Digital transmission<br>Pulse-code modulation | Satellite communications<br>Microwaves<br>Networking<br>Optical fibers<br>Packet switching | Integrated systems digital network (ISDN) | |
| Computer hardware | Vacuum tubes<br>Magnetic drum<br>Cathode ray tube | Transistors<br>Magnetic core memories | ICs<br>Semiconductor memories<br>Magnetic disks<br>Minicomputers<br>Microprocessors | Distributed computing systems<br>VLSI<br>Optical disks<br>Microcomputers | Advanced packaging and interconnection techniques<br>Ultralarge-scale integration<br>Parallel architectures<br>3-D integrated-circuit design<br>Gallium arsenide semiconductor technology<br>Optical components |
| Computer software | Stored programs<br>Machine code<br>Autocode | High level languages<br>COBOL<br>ALGOL<br>FORTRAN | Very high level languages<br>Structured programming<br>Time-sharing<br>LISP<br>PROLOG<br>Computer graphics | Ada<br>Widespread packaged programs<br>Expert systems<br>Object-oriented languages | Concurrent languages<br>Functional programming<br>Symbolic processing (natural languages, vision, speech recognition, planning) |
| Computer performance | 2 Kilobyte memory<br>10 Kiloinstructions per second | 32 Kilobyte memory<br>200 kIPS | 2 Megabyte memory<br>5 Megainstructions per second | 16 Megabyte memory<br>30 MIPS | 1 Thousand to 1 million MIPS |

*Adapted with permission from Kahn RE. A new generation in computing. IEEE Spectrum 1983 Nov:37. ©1983 IEEE.

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## Basic Technologies

Today the basic technologies that support the information society correspond roughly to the four areas within information technology: the area of computation has been driven by the miracles of microelectronics; the area of communication has come of age through developments in networks; the area of data bases depends on advances in data storage technology; and the area of the user interface is making progress as a result of software advances, new input and output devices and accomplishments in artificial intelligence (AI). This last set of basic technologies we shall lump together, under the heading *amenities*, those devices and computer programs that make for a pleasant and productive interaction between user and machine.

### *Microelectronics*

**The silicon chip.** At the root of the information society today is the silicon chip. Its elegance, efficiency and economy have not only produced the miracles of computation well known to all, but also fueled the transformations occurring in networks, data bases and user amenities. As most readers know, microscopic patterns of conductors, semiconductors and insulators are laid down using photographic techniques on highly purified silicon wafers, typically from 3 to 6 inches (7.6 to 15.2 cm) in diameter and less than 1 mm in thickness.

The conductors have line widths of 1 to 2 $\mu$ in today's integrated circuit technology and a square less than 10 $\mu$ on a side can enclose circuitry sufficient to store a single bit of information. Integrated circuit storage devices, commonly called memories, are beginning to appear with the capacity to store 1 million bits. These memories are fabricated by laying down the memory pattern over and over on a thin silicon wafer and subsequently dicing the wafer into about 100 chips, each about 1 $cm^2$ and each containing a complete 1 million bit memory. Two kinds of memory chips should be distinguished, ROM and RAM. ROM stands for *read only memory*, information storage that cannot be altered without special procedures. RAM stands for *random access memory*, easily alterable memory that can access any specific location as easily as any other.

**Computers.** Complete computers on a single silicon chip are available that include the central processing unit, the memory (both ROM and RAM) and the input-output system, but more common is the *microprocessor*, a computer without memory and with only limited input-output capability. Memory and input-output chips can then be added to the microprocessor in numbers sufficient to suit a particular application. Both the single chip computers and the microprocessors are organized along the same lines as John von Neumann proposed (1) in 1946. Most of the computers built during the intervening years have been similarly organized, giving rise to the phrase "von Neumann architecture" to describe this dominant approach to computer structure. Recent research (2) has emphasized new architectural approaches aimed at better utilization of microelectronic technology.

**Computer system characteristics.** The particular microprocessor chip used in a computer system determines the family to which it belongs and the system's most basic characteristics. Well known families are those built around the Zilog Z80 chip, which was used by many early personal computers (PCs); the MOS Technology 6502, chosen as the basis of the Apple II; the Intel iAPX 86 family used by the IBM PC and PC-compatible machines; and the Motorola 68000 family found in the Macintosh from Apple, in the Amiga from Commodore, in the 520ST from Atari and in many new, powerful workstations. Important characteristics of the processor are its clock frequency (the number of repetitions of its simplest operation that can be carried out per second), the number of bits used in the internal data pathways of the arithmetic/logic unit and the number of bits used by the bus (external data pathways used for input-output operations). The number of bits used by a data pathway is commonly called its width so a microprocessor like the Z80 is said to have an 8 bit wide arithmetic/logic unit and also an 8 bit wide bus. A sequence of 8 bits is also called a byte so the Z80 could be said to have a one byte wide arithmetic/logic unit and bus. The Motorola 68000 has a 32 bit wide arithmetic/logic unit, but only a 16 bit wide bus. The more powerful Motorola 68020, a recently introduced microprocessor in the same family, has an arithmetic/logic unit and a bus each 32 bits wide. Clock frequencies for the most recently introduced microprocessors exceed 20 MHz. Wider data pathways and faster clocks lead to more powerful computers.

Miniaturization in electronics has produced almost a millionfold reduction in central processing unit cost in about three decades. In its present state of development this technology is called *very large scale integration (VLSI)*. It is a remarkable achievement, producing profound changes in the way computers are used in society. Once highly centralized, computers are now highly distributed. Once so expensive that the cost of their support equipment was hardly noticed, computers must now share that support equipment. Whereas digital communication was used only to bring raw input data to a centralized computer facility, it is now used for a broad spectrum of intercomputer transactions.

### *Computer Networks*

**Transmission of digital information.** Early computer communication was achieved through the adaptation of voice telephone lines to digital service. A modem (a modulator/demodulator pair) converted the on/off digital signals to and from a form more suitable to the limited bandwidth of voice grade telephone lines. Telephone equipment itself, over the years since the introduction of integrated circuit devices, has been converted to digital signal processing. Thus, information sent today by digital telecommunications often encounters the anomalous fate of being converted to a voice-like form only to be converted back to digital form for switching at a telephone central office. The reverse conversions take place on leaving the central office for transmission of the digital information to its destination. As more of the nation's telecommunications become fundamentally digital, the need to adapt to an outmoded communication medium will disappear. Anticipating this change, many networks have already been developed that are specialized for the transmission of digital information.

**Local area network technology.** A local area network links computers and computer resources within the premises of a company or an institution and is usually only a few blocks to a few kilometers in extent. Computers and computer resources are located at network nodes that are connected to each other by coaxial cables or glass fibers. These transmission media provide reliable, high speed data links over the short distances involved in a local area network. This technology was pioneered at Xerox and led to Ethernet (3), the earliest application of the local area network concept.

Visions of lucrative applications to office and factory automation have fueled the development of a variety of local area network approaches. The inevitable tower of Babel that results from multiple independent approaches to communication has been partially limited by the development of a set of local area network standards by the Institute of Electrical and Electronic Engineers (IEEE). The IEEE 802 Committee has produced three standards, 802.3, 802.4 and 802.5, specifying the physical and data link properties of three competing approaches to the method of controlling a node's access to the local area network.

**IEEE standards.** Ethernet, as specified by IEEE 802.3 (4), achieves access control within the local area network by allowing each node to contend with all the other nodes through a procedure called "carrier sense multiple access with collision detection" (CSMA/CD) that is quite similar to the way participants in a conversation avoid the garbled speech that occurs when more than one person talks at a time; two people may start to talk simultaneously, but usually after a short interval one has gained control of the conversation. This IEEE standard based on Ethernet is the earliest to be published of the three and is widely used in office automation.

*The second and third approaches,* specified by IEEE 802.4 (5) and 802.5 (6), use a scheme for network access control called a token. This is a brief message passed from node to node in the network. Only when a node has the token can it gain access to the network. This scheme ensures that only a single node at a time can transmit information on the local area network and eliminates the possibility of garbled messages. IEEE 802.5 specifies the passage of the token around a physical ring of nodes, and is the network strategy preferred by IBM. IEEE 802.4 transmits the token from node to node in the local area network in a defined but arbitrary order. This *token-bus* approach loses some of the simplicity of the *token-ring* approach, but gains considerable flexibility in the manner in which the network can be laid out. IEEE 802.4 is known as the Manufacturing Automation Protocol and has been championed by General Motors. This protocol will undoubtedly play a major role in the automation of manufacturing in the future.

Each of the IEEE 802 standards provides an access control means so that multiple network nodes can share a single wide band transmission medium. Intercomputer communication traffic occurs naturally at high data rates and in bursts that can be organized into short groupings of bits called packets. These characteristics are well suited to a shared channel and to a transmission rate of 1 to 10 megabits per second (Mb/s), characteristics specified by these standards. Commercial equipment is available satisfying IEEE 802.3 that uses either baseband transmission (no carrier frequency) or broadband transmission (multiple carrier frequencies assignments on a cable television-like medium).

**International network standards.** Local area networks have limited geographic coverage (a few kilometers), and computer communication requiring metropolitan, national or global coverage must depend on common carrier networks. In the developed countries these networks are rapidly converting to integrated services digital networks (ISDN) with transmission rates one to two orders of magnitude greater than the present few kilobits per second (kb/s) that is now available over voice grade lines. Present standards include the X.25 packet switching protocol developed by the International Telegraph and Telephone Consultative Committee (CCITT). Much work beyond X.25 remains to be done and this consultative committee will play a key role as integrated services digital networks are installed throughout the world.

*The interconnection of computer networks* (including both local area networks and integrated services digital networks) will require a standardization effort at a more abstract level than the physical and data link standards developed by IEEE and the ITT Consultative Committee. To meet this need the International Standards Organization has developed a reference model of network communication as a first step toward the international standardization of various communication protocols. This Open Systems Interconnection (OSI) reference model divides the problem into seven layers covering, for example, the physical aspects in the least abstract first layer and application issues in the most abstract seventh layer. This stratification of concerns has made it possible to organize the various standardization efforts in an effective manner. For example, different communication protocols in International Standards Organization levels 3 through 7

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can operate concurrently on a single physical network specified in International Standards Organization levels 1 and 2 by IEEE 802.3. Products and standards are now beginning to fall into place and computer networks are, at last, a practical reality.

## *Data Storage*

At the beginning of the electronic computer era in 1946, J. Presper Eckert and John von Neumann recognized that data storage for the ENIAC would have to be arranged in a three level hierarchy (7). Today for personal computers a three level storage hierarchy is still with us. For mainframe computers the storage hierarchy has grown in complexity to seven levels spanning the range from fast and expensive (semiconductor memory chips) to slow and cheap (optical disks for archival storage). The first level of this hierarchy is directly connected to the central processing unit while the remaining levels are connected as peripheral input-output devices and are generally called secondary or archival storage. The trend toward miniaturization in electronics produced the remarkable advance in memory chip capacity described, but surprisingly, developments in other storage technologies have kept pace. This is particularly true in secondary storage devices that utilize either magnetic or optical read/write heads to sense and store the patterns of digital information on the storage medium.

**Magnetic storage technology.** To date, magnetic storage devices have been more prevalent than all other technologies combined. For on-line storage, mainframes and minicomputers have used rotating stacks of thin plastic platters coated with a magnetic film. The motion of these disk packs is imparted by the rotation of a central spindle, typically turning at 3,600 rpm. Multiple read/write heads move radially to access information stored on concentric circular tracks. These magnetic disks have the advantage of immediate playback, immediate reuse and long-term storage. An equally important quality is reliability; thus the trend has been away from operator-removable disk packs, which have proved to be bulky, expensive, fragile and extremely sensitive to environmental contaminants. A controlled environment can be obtained by sealing the spindle, disk pack and the read/write heads into a rugged, encapsulated package. This arrangement prevents removal of the disk pack and, consequently, is called a fixed disk.

One of the major developments in magnetic storage technology during the last decade has been the introduction of the Winchester disk, a fixed disk with lower cost per bit and higher reliability than its predecessors. This development requires "flying" the read/write heads on a microscopic air cushion over the rotating disk surface. Winchester disks are distinguished by the encapsulation associated with a fixed disk and by the reduced size of the aircushion that is possible when the head "takes off" from the disk surface. Disk drive capacities depend on the diameter of the disk and on the number of platters in the stack. Standard diameters are 3.5, 5.25, 8 and 14 inches (8.89, 13.3, 20.3 and 35.5 cm) with capacities today that range from 5 megabytes (Mbytes) to 1 gigabyte (Gbyte) of data. Storage densities have grown since the introduction of the technology and will grow substantially in the future before fundamental limits are reached.

Fixed disks are a useful form of storage for data that must remain available to the central processing unit (on-line) at all times, but some form of removable storage is needed to provide backup storage for on-line files and to provide inexpensive storage for little used files. Reel-to-reel, ½ inch (1.27 cm) tape has been the industry standard for removable storage during the past three decades.

Although the capacity and performance of industry standard tape drives have improved by several orders of magnitude over the years, new technology is now challenging their preeminence. Streaming tape, floppy disks and tape cartridges are each vying for a share of the removable storage market.

*Streaming tape drives* substitute microelectronics for the complex mechanical components of industry standard tape drives. Instead of actually starting and stopping the tape to accommodate an uneven flow of data, the streaming tape drive stores incoming data in a buffer memory and adjusts tape speed to match the average data rate. The elimination of mechanical components reduces the cost and greatly reduces the size of these new tape drives.

*Thin, flexible mylar disks* that rotate in a paper or plastic envelope are properly called diskettes, but are familiarly called floppy disks. In personal computers they are used for both on-line and archival storage. Floppy disks are slow and have limited capacity, but they are cheap, simple and reliable. There are three standard sizes that agree with the Winchester disk sizes, 3.5, 5.25 and, the almost obsolete, 8 inches in diameter. Unfortunately, most personal computer manufacturers write the data on these disks in quite different ways and, as a result, the capacity of a diskette varies not only with its diameter, but also with the brand. It is rarely possible to read a diskette on one brand of personal computer that had been previously written on another. Diskette capacity varies from 160 kbytes to over 1 Mbyte.

*Tape cartridges* come in ¼ and ½ inch (0.635 and 1.27 cm) sizes and are capable of storing up to 100 Mbytes of data. They share the advantages and disadvantages of industry standard and streaming tape drives: inexpensive media and long access times while the tape moves to the desired position.

**Optical storage technology.** Although magnetic storage has dominated the field for 30 years, a new contender, the optical disk, is moving out of the research and development laboratories into the marketplace. The technology used for compact disk (CD) audio recording is now available for storing digital information. These disks have a 600 Mbyte capacity, are inexpensive and very compact. Information can be read from, but not written to, these optical disks and as a result they are called CDROMs. A more expensive variation of optical disk technology, now being introduced, partially removes this limitation by making it possible to "write-once and read-many" times. Both CDROM and WORM optical disks have data transfer rates about an order of magnitude lower than Winchester disks, but the low media cost and the high capacity of the optical technology make it a very attractive alternative where information storage is not volatile. For example, WORM technology can be used for archiving medical records or radiologic images where an audit trail or a permanent record is desirable. Optical disks are likely to revolutionize many aspects of education because of their vast capacity, low cost and ability to store images as well as text, an ideal combination for interactive teaching. One application of the technology now available is a CDROM published collection of the latest information on the diagnosis and treatment of certain rare cancers.

### *User Amenities*

The basic technologies described provide the physical aspects of a modern computer system, but without software and special input-output devices to interface the system with the user it is hardly more useful than ENIAC. Without this user interface few people can deal with the unforgiving and hostile nature of a bare computer system. Even those who deal directly with a computer on its own terms (endless strings of 1 and 0) find that their productivity and capacity to accomplish their goals is markedly curtailed. Over the last three decades scores of computer languages, operating systems, integrated environments and input-output devices have been developed to bridge the gap between the computer and its user. There is, however, a long way to go before a large fraction of the public will find dealing directly with a computer tolerable, let alone pleasant and helpful. We next review some of the steps that have been taken so far.

**Computer software.** Computer programs, lists of step by step instructions to be interpreted by the computer, are today usually written in languages convenient for the programmer. These *high level languages* are subsequently translated by another computer program into the machine's language. High level languages are not like English, but have a very restricted snytax that can be interpreted unambiguously by the translation program and, if correctly written, unfailingly yield the proper machine language. Good high level languages simplify the task of the programmer by handling all routine housekeeping jobs, by producing a resulting program that is readable and by producing a portable program, one that can easily be transferred to a computer of another type. Programming languages are usually partitioned into procedural languages and declarative languages. Procedural languages have been known for three decades and specify the computer's sequence of actions much as a recipe specifies a cook's actions. Most of the better known languages fall into this class: BASIC (8), COBOL (9), PASCAL (10), FORTRAN (11), FORTH (12) and LISP (13). These languages are designed to run on classical von Neumann machines and to deal with administrative, engineering and numerical tasks.

*PROLOG.* The most widely adopted declarative language is PROLOG (14), a language designed for manipulating logic statements. In contrast to a procedural language, PROLOG allows the computer to achieve the result specified by a logic statement without the need for the user to specify the means. Developed in England and now widely in use in the academic community in the United States, PROLOG has been most enthusiastically accepted in Japan, where it is the primary language of their government-supported effort to develop fifth generation technology (15).

*Interpreters and compilers.* Programs used for the translation of *source code* (the high level language produced by the programmer) into machine language are of two kinds: interpreters and compilers. Interpreters translate each line of source code anew for each execution of the program; compilers translate the source code only once, producing an *object code* in machine language form that can subsequently be reused without repeated translation for each execution of the program. The object code produced by compilers can be highly optimized for a specific machine and will execute much faster than the same program executing through an interpreter. On the other hand, interpreters often have many more amenities than compilers, making the former easier to use since the programmer's work can be tested as the program is written. Some modern compilers have many of the advantages of interpreters, so that languages like PASCAL, although compiled, can be as convenient to use as the popular beginner's BASIC interpreter.

*Fourth generation languages.* The huge market for personal computers has spawned a new set of programming tools called *fourth generation* languages. These languages operate at the command level used in various popular program packages. Because of the potential for high volume sales, many software vendors have invested enormous effort in the amenities for these packages. For example, *Visicalc,* probably the best-selling software product in the world, allows the user to prepare a spreadsheet made up of rows and columns of interdependent figures in a way that agrees so well with intuition that a beginner can often master it without lessons or a detailed instruction book.

*Computer operating system.* The control and allocation of the various resources available to a computer system are the responsibility of the computer's *operating system.* This complex set of programs manages the allocation of the computer's memory, assigns central processing unit cycles to processes ready for execution and controls input-output activity on the computer's bus. The operating system makes it possible for the user's programs (usually called application programs) to communicate with various peripheral devices, with secondary storage devices and with other computers by means of a computer network. A good operating system will provide the programmer with a consistent and simple interface to the system. An excellent operating system will provide such superior services to the application programmer that the user's view of application programs will also be consistent and simple.

Operating systems may be proprietary (produced by a single manufacturer) and may be restricted to one machine family. A recent trend, particularly for minicomputers and personal computers, is the increasing popularity of operating systems, such as UNIX, MSDOS and UCSD-p System, that have been ported to many different computer systems. The portability of an application program is markedly enhanced if it can run under one of these popular operating systems.

*Integrated environments.* Program packages such as Visicalc are often superimposed on an operating system, forming a kind of super operating system or *integrated environment* for the user that leads to an improved and consistent user interface. On many personal computers today these packages can produce a simulation of a desktop environment in which the equivalent of multiple pieces of paper and multiple folders (or files) of data are presented on the computer video display. The ability to switch rapidly from one piece of paper at the top of the desktop stack to another through the manipulation of *windows* on the video display is a significant characteristic of these packages.

*A very important part of an integrated environment is file handling ability.* The storage technology described in the previous section must be tamed by the operating system allowing the user to easily open a file no matter where it is stored; read, search or modify the file; and finally close the file and return it to the proper place in storage. The power of an integrated environment with good file handling can be appreciated when one realizes that a file may contain source code, a chapter of a book, this manuscript, a portion of a digitized electrocardiogram, object code or anything that can be represented by a finite string of alphanumeric characters. Unfortunately, different operating systems, and thus different integrated environments, have different conventions for storing files. They are compatible with each other only with the aid of special translation programs. Hence the trend away from proprietary operating systems.

**Input-output devices.** Since 1946 input-output devices have come a long way toward doing their part in providing the needed user amenities. Originally ENIAC was programmed by rearranging wires on a plug board. Later punch cards were imported from the world of business machines, where they had been in use for more than 60 years. Invented by Hollerith for the processing of data from the 1890 U.S. census (16), they had matured over the years at the hands of IBM. The introduction of the cathode ray tube as a computer output device in the early 1950s led to today's video displays. The forerunner of the personal computer was developed by Clark and Molnar in 1962 (17). Its input-output devices were similar to the keyboard, floppy disk and video display found on most of today's personal computers. None of these are really well suited to the job. The keyboard requires a skill not possessed by all and made more difficult to acquire by the QWERTY layout developed a century ago to avoid mechanical tangles of the keys. The floppy disk has slow transfer rates and limited storage capacity. The video display is not as convenient to read as hard copy, is tiring for the neck and back and usually limited to alphanumeric text.

*Pointing devices.* New input devices have become popular, largely as a result of the small fraction of personal computer users who find the keyboard easy to use. A pointing device such as a mouse or a trackball allows the user, with one smooth motion of the hand, to pick out for attention a character or a small region of the video display screen. A touch sensitive screen is a form of pointing device that has been in use for over a decade and has been particularly popular in medical applications.

*Bit-mapped displays.* Video displays have improved with the introduction of buffer memories that store a single bit for every picture element (pixel) displayed on the screen. These displays are called *bit-mapped* displays and they allow a major improvement in the display flexibility over the previous character-oriented displays. Graphics and windows are two of the results of this technology and they are demonstrated admirably in the Macintosh, Amiga and 520ST personal computers.

*Printers.* Computer output in hard copy form is produced most often by printers although plotters are used for high quality graphic output. Printers fall into three categories that are roughly correlated with price: draft, letter and publication quality. Draft printers are the least expensive and use some form of dot matrix to form the printed symbols. The most popular scheme is a matrix of tiny pins that strike a typewriter ribbon when actuated by an electromechanical transducer. A newer and quieter scheme is a matrix of tiny ink jets that are mounted in a replaceable cartridge. Some of these matrix printers approach the quality of a good typewriter, that is, letter quality, and some produce quite adequate graphics. Letter quality printers use the impact of type wheel or ball against a ribbon to produce printed symbols similar in all respects to those produced by an office typewriter. The newest and most expensive of the three categories is the laser printer, which uses xerographic techniques to produce printed symbols of a quality normally associated only with typeset copy suitable for publication. With adequate software and image memory a laser printer can also produce very high quality graphics.

## Future Trends

The division between a description of state of the art technology and a prediction of future trends is somewhat arbitrary, particularly for those developments that are now in the laboratory or are just beginning to appear in the marketplace. We have chosen to include here those technologic developments for which there is considerable growth potential. Thus, although there are some products already on the market in speech recognition, voice synthesis, expert systems, computational imaging and scientific workstations, we expect these areas to have enormous future potential for medicine in general and for cardiology in particular.

### *Basic Technologies*

Trends in the four basic technologies outlined will continue. Microelectronics will move to higher densities and larger chip sizes. Instead of doubling chip complexities every year, as was the case from 1960 to 1975, the semiconductor industry is on a course that will double chip complexity only every 2 years (18). Already 4 million-bit memories are being developed in the laboratory and several more doublings in complexity beyond that achievement can be expected before fundamental physical limits are encountered. By the end of the century, integrated-circuit devices with 100 million transistors should be on the market. This could mean lap top computers with the power of today's supercomputers and semiconductor memories with the capacity of today's hard disks.

**Optical fibers.** Computer networks will slowly move to glass fibers as electrooptical technology matures. Fibers are fundamentally superior to copper cables because they are cheaper, have capacity for data rates higher by several orders of magnitude, are insensitive to electromagnetic interference, are more secure and take up less space. Problems at the interface between electronic systems and optical fibers will give coaxial cable technology a number of years of useful life before it is displaced by fiber. Data rates on local area networks will grow faster than on common carrier networks. Local area networks with the ability to transmit pictures will become commonplace within this decade as a result of the driving force of electronic radiology (19). Although the telephone companies are installing glass fibers throughout their systems, it will take many years to convert the entire telephone plant. Connections to subscribers' offices and homes will be installed only after connections between central offices have been completed. In summary, more digital communication at lower cost is on the way. Standardization will lead to more and cheaper network products so that computer networks will become a fundamental part of all computing.

**Newer storage devices.** The major trend in secondary storage will be toward the incorporation of more microelectronics so that the physical devices themselves can be simpler, cheaper and more reliable and so that the host computer system can deal with a hierarchy of storage devices in a more uniform manner. Storage densities will continue to increase for both magnetic and optical technologies. We estimate that the contenders in the hierarchy will be: optical ROM disks, magnetic tape, optical WORM disks, erasable optical disks, Winchester cartridge disks, Winchester fixed disks and semiconductor chips. The order of these seven contenders is from the least to the most expensive per bit of storage. For the most part, this also orders the contenders from the slowest to the fastest access time.

**Integrated environment and desktop publishing.** Beyond the major developments discussed in the next sections, we see two other trends in the amenities: integrated environments and desktop publishing. The trend will continue toward the integration of the programming language, communication and data base environments into one uniform interface with the user. These changes will be driven by the personal computer marketplace, but will be likely to be based on developments in academic computing. Graphics, icons and even pictures will be featured so that ease of use will be promoted by intuitive rather than rote understanding of the operation of the system.

*The inexpensive laser printer will trigger an abundance of software development for the new field of desktop publishing.* Publication quality copy can now be produced by the combination of a personal computer and a laser printer and this fact will generate an entirely new market segment. Physical pasteup will be replaced by soft copy pasteup on a personal computer's video display. Data bases integrated with the desktop composition system will store the raw copy including graphics and halftones ready for pasteup. These developments in desktop publishing along with those in networks will undoubtedly have profound implications for the preparation and publication of scientific results. It is not clear what the eventual effect on traditional journals will be, but some editors will soon begin accepting camera-ready copy in electronic form that includes graphics and halftones.

### *Speech Recognition and Voice Synthesis*

The understanding of continuous speech by computer is still a distant goal, particularly if the speech is produced by a wide variety of talkers. Until the end of the century progress toward this goal is likely to be slow and steady, without obvious scientific breakthroughs. On the other hand, isolated word recognition for limited vocabularies is here today. Several research laboratories have phone numbers that will connect anyone wishing to call with a computer having the capability to identify, with accuracies exceeding 90%, any of the spoken digits from zero through nine. There are, in fact, inexpensive peripheral devices for personal computers that allow the user to train a computer to recognize a few hundred isolated words spoken by a single talker.

Uses in the cardiac catheterization laboratory and in overreading electrocardiograms seem likely.

**Voice output methods.** Voice output from computers is familiar to anyone who has called for operator assistance with an unknown telephone number. There are two basic methods of voice output which may be distinguished by the naturalness of the result. The more natural voice output method uses recorded or hand-edited human speech elements stored in compressed form. The more compression used in storing the speech the less natural it sounds when reproduced. The second method of voice output synthesizes the speech from either a sequence of phonemes or from a natural language text file. This method allows a vocabulary of unlimited size, is more flexible and uses less computer storage, but results in speech that is less pleasant. Some personal computers now have the ability to produce a synthesized vocal version of text files. At least one personal computer can store and reproduce a small amount of natural speech. A talking self-test system for diabetics was recently offered commercially (20). The potential for communicating with computers through speech is exciting and will surely expand greatly in the years to come.

### *Artificial Intelligence and Expert Systems*

**Artificial intelligence.** Since the phrase was coined by John McCarthy in 1956, Artificial Intelligence, or AI as it is frequently called, has been the center of excitement and controversy. Winston (21) defines artificial intelligence as "the study of ideas that enable computers to be intelligent." A more cynical view is that artificial intelligence is defined by what the people in the field do. The leaders of the field see the rapid deployment of artificial intelligence techniques to medicine, business, manufacturing and education (15). Detractors say that "artificial intelligence has failed to live up to its promise and there is no evidence that it ever will" (22). As usual, the truth lies between the extremes. There are many accomplishments today of practical value, but fundamental problems remain. To be listed among such accomplishments are logic programming (23) (in languages such as PROLOG), programs that solve mathematical problems symbolically (24), data base query languages with capabilities for deduction (25) and expert systems (15). A fundamental problem that we see is the absence of diversity in artificial intelligence systems—diversity of the kind that makes living systems resilient and when restricted leads to fragility. A second fundamental problem is the inability of artificial intelligence systems to explain their actions. Some early results have been achieved in explainable systems (26), but much work remains to be done before a robust solution to this problem is obtained.

**Expert systems.** These computer programs solve problems by employing reasoning tasks based on the encoded knowledge of human experts coupled with the deductive capability of a powerful *inference engine*. This inference engine may be realized by incorporating the rules of logic in a computer program or by building a special processor well suited to logical reasoning.

In applications where the domain of knowledge is circumscribed, such as locating cable faults in a telephone plant, expert systems have demonstrated practical usefulness. Work continues on programs to carry out medical diagnosis (27), but the ability to explain results fully remains elusive. Nevertheless, expert systems are likely to appear in many cardiology settings (28–30).

### *Computational Imaging and the Scientist's Workstation*

**Computational imaging.** This is the union of the three fields of image processing, computer vision and computer graphics. Previously separate, these three fields are now merging their technical capabilities. They now each use raster graphic displays; furthermore, microelectronic devices will soon be available that will allow the integration of special computational and input-output requirements from each of the fields into a single inexpensive system. For years ultrasound echocardiography has been used to image the beating heart and computed tomography and nuclear magnetic resonance imaging have recently been applied to this same task. Results of all three imaging modalities are certain to improve in the next few years. Thus, it seems reasonable to predict that computational imaging will become of increasing importance to the cardiologic investigator and diagnostician.

This view may seem farfetched because of the present cost of computational imaging systems, but consider the following trend. In 1970, a handful of integrated circuit memory chips could store enough characters to fill a video display screen. The era of the ubiquitous alphanumeric computer terminal began. In 1980, a handful of memory chips could store enough graphic information to fill a screen. The era of the personal computer began. By 1990, a handful of chips should be able to store a high quality image of the heart. Disk transfer rates should be fast enough to give the illusion of smooth movement of the image. If systems that produce such images are as plentiful as today's personal computers, what are the implications for clinical practice and research?

**Cardiologist's workstation.** This leads us to our last topic, the scientist's workstation. It differs from personal computers in several ways (31). First, a workstation is fundamentally part of a computer network. It depends on the network for information and for certain resources that are not needed locally. Second, the workstation may be thought of as a well thought out kit of information-handling tools. Finally, the workstation will be capable of smoothly managing large files and data bases, even ones that exceed the capacity of local secondary storage. The personal computer was a step along the way and the scientist's workstation is a significant additional step.

*Both diagnosis and research depend heavily on pictures;* in addition to the imaging modalities already mentioned, electrocardiograms, chest X-ray films, angiograms, tissue sections, nuclear medicine images and many more can be listed. The use of computers in cardiology has been handicapped by the absence of a readily available capability to present, analyze and quantify images. We believe that, for computers in cardiology, the most important trend in information technology is the evolution of a high performance workstation for cardiologists, one capable of presenting high quality pictures, analyzing these images and quantifying the results.

## Glossary

The field of information technology is suffused with acronyms and abbreviations. So many new concepts requiring unambiguous technical names have been introduced that these compact forms have become an important part of the vocabularly of information technology. Below, the compact and expanded forms are listed together.

| | |
|---|---|
| ACM | Association for Computing Machinery |
| AI | Artificial intelligence |
| ALU | Arithmetic-logic unit |
| CCIT | International Telegraph and Telephone Consultative Committee |
| CDROM | Compact-disk read-only memory |
| CPU | Central processing unit |
| CSMA/CD | Carrier sense multiple access with collision detection |
| ENIAC | Electronic numerical integrator and calculator |
| IC | Integrated circuit |
| IEEE | Institute of Electrical and Electronics Engineers |
| IO | Input-output |
| ISDN | Integrated services digital network |
| ISO | International Standards Organization |
| LAN | Local area network |
| LINC | Laboratory instrument computer |
| MAP | Manufacturing automation protocol |
| MOS | Metal oxide semiconductor |
| OSI | Open system interconnection |
| RAM | Random access memory |
| ROM | Read-only memory |
| VLSI | Very large scale integration |
| WORM | Write-once read-many times |

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